MODELING AND FORECASTING METHODS

Web site references are provided where available.
This document is adapted and expanded from the FHWA Toolbox for Regional Policy Analysis (http://www.fhwa.dot.gov/planning/toolbox/index.htm).

Forecasting Land Development Patterns

Method 1. Proximity-Based Forecasting

This approach forecasts land development based on proximity to highway or transit facilities. It is based on regression or other statistical analysis of historical development data that relates land development to proximity to major transportation facilities such as arterials, interstate highways, or rail transit stations.

Sanchez (1999) uses remote sensing and statistical models to relate highways to land development in Oregon. A growth trend analysis is performed using a GIS to overlay the extent of urban development for cities over time (derived from aerial photography). Regression analysis is used to relate development to proximity to highway projects. In conjunction with case studies, the combined results are being used to prepare a methodology that the Oregon DOT can apply during the highway impact assessment process when considering potential land use changes.

The **Land Transformation Model** (Pijanowski) (http://www.ltm.msu.edu/) uses a probability-based approach to predict urban land conversion in Michigan. The primary focus of the project is on coupling land use change and hydrogeologic and geochemical processes. Land conversion is forecast in part based on proximity to urban infrastructure.

Method 2. Delphi/Expert Panel

A group of "experts" including local officials, developers, academics, etc., is gathered to predict the land development impacts of a project. Applications of this approach include U.S. 301 in Maryland (Porter et al., 1997); Santa Clara County, CA (Cavalli-Sforza and Ortolano, 1984); and guidance provided by the Wisconsin DOT (WisDOT, 1993).

Method 3. Accessibility-Based Forecasting

Quantitative accessibility measures, derived from travel demand models or other sources, are used to estimate changes in development.

Hirschman and Henderson (1990) use a gravity-based accessibility measure to forecast land use impacts of highway improvements. A gravity model is developed to predict residential location decisions based on employment accessibility. Employment accessibility for residential zones is calculated based on highway network travel time data from the travel demand model.

Method 4. Simple Land Use Models

Simple land use models consist of sets of equations to forecast land development by zone, using a limited amount of data for model calibration and inputs. While accessibility is a primary driver of development in these models, other factors may also be included to the extent that data are available.

HLFM II+ is a relatively simple forecasting model that relies on spatial interaction (accessibility). It is designed for smaller MPOs with small budgets and staff for land use modeling. An example of its application to Vancouver, Canada is described in Rice (1998). The Capital District Transportation

Commission developed a land use model for Albany, NY (see Albany case study). The model consists of a set of three equations to predict incremental residential and employment development. Development is forecast based on accessibility, historical development trends, home prices, and property tax rates.

Method 5. Complex Land Use Models

More complex land use models have been developed to model a larger range of factors and relationships that affect land development. These models may contain both a transportation and a land use modeling component, or they may consist of a land use model that interfaces with an existing regional travel demand model. They typically cover an entire metropolitan region and consist of a zonal structure, similar to travel demand models. Consistent with regionwide forecasts of population and employment, they allocate development to each zone based on transportation accessibility, land prices, available land by development type, and/or other parameters. The models are typically calibrated using historical data on land development, prices, transportation accessibility, and other factors.

DRAM/EMPAL is the most widely applied model in the U.S. Other examples of recent U.S. applications include: **UrbanSim** (Waddell, 1998) (http://www.urbansim.org/) is an integrated transportation-land use model that is being applied in Portland, Oregon; Salt Lake City, Utah; and Honolulu, Hawaii to test alternative regional land development scenarios and transportation policies. The model implements a perspective on urban development that represents a dynamic process resulting from the interaction of many actors making decisions within the urban markets for land, housing, non-residential space and transportation. By treating urban development as the interaction between market behavior and governmental actions UrbanSim is designed to maximize reality, thereby increasing its utility for assessing the impacts of alternative governmental plans and policies related to land use and transportation.

The Baltimore Metropolitan Council (Liu, 1998) is modeling the impacts of Smart Growth policies using **TRANUS** (http://www.modelistica.com/modelistica.html), an integrated transportation/land use model. TRANUS has also been applied by the Oregon Department of Transportation for a statewide modeling project (cf., Donnelly and Upton 1998, or Oregon Department of Transportation Modeling Program.)

MEPLAN (http://www.meap.co.uk/meap/ME&P.htm) has been applied in Sacramento, CA to test the impacts of a variety of regional transportation and land use scenarios (see Sacramento case study). MEPLAN also has been widely applied in Europe to model metropolitan land use patterns (see the SPARTACUS case study). Other models and applications are discussed in Parsons Brinckerhoff Quade and Douglas (1999).

Comparing Alternative Development Scenarios

PoleStar (http://www.seib.org/polestar/index.html) was developed by the Tellus Institute, a non-profit research and consulting organization that develops and applies analytical software packages in the environmental field. The PoleStar software system is a scenario-building tool. The PoleStar System is applicable at national, regional and global scales. You can customize data structures, time horizons, and spatial boundaries-all of which can be expanded or altered easily in the course of an analysis. The system accepts information generated from formal models, from existing studies, or any other sources you wish to draw upon.

Smart Places (http://www.smartplaces.com/) is a tool for geographic decision-making. SmartPlaces enhances decision-making insight in target marketing, economic development, land-use planning, transportation systems, facilities management, environmental remediation and protection, energy forecasting, water allocation, and resource control. SmartPlaces is used to evaluate the implications and opportunities of alternative plans. It offers innovation in the planning process through interactive design, evaluation, and illustration of proposed activities. The system runs on a PC using ESRI's ArcView software. Smart Places provides a user approachable set of tools for the exploration, design, modification, illustration and evaluation of alternative planning scenarios. Smart Places is a GIS-based software package developed by the Electric Power Research Institute (EPRI), a research consortium with a focus on the generation, delivery, and use of electricity.

Smart Places is designed to support communities considering the implications of alternative land use plans. One of its first applications was to the redevelopment of the Stapleton Airport site in Denver, Colorado, after the new airport opened in 1995. Seven resource features are included in Smart Places: land use, energy, transportation, communications, water, wastewater, and solid waste. Smart Places can be modified to include other features as well. Smart Places allows for scenario (what-if) analysis by computing different development scenarios. Smart Places allows the community to evaluate key community performance measures and how performance might be affected depending upon the type of development pursued. For example, one could use Smart Places to calculate energy requirements for a development of 50 versus 100 single-family homes. Through its interactive design, it prompts the user with specific questions about the average floor space, heating systems, etc.

EPA is developing two computer software decision support tools for planners and communities. **DIET (Designing Industrial Ecosystems Tool)** (http://www.smartgrowth.org/library/DIET.html) is designed to aid decision makers and planners in identifying industrial facilities that exhibit economic and environmental potential for eco-industrial development (e.g., eco-industrial parks). Input factors into the model include area available at the site, number of facilities needed at the park, available energy and water sources, pollution constraints, and zoning restrictions. DIET is intended to allow "what-if" analysis by estimating trade-offs among environmental, economic, and employment opportunities under different eco-industrial park planning scenarios. Another EPA decision support tool under development is **FaST (the Facility Synergy Tool)** (http://www.smartgrowth.org/pdf/fastflyr.pdf), which can be used alone or in conjunction with DIET. FaST is used to identify potential materials exchange, energy trading, and purchasing coordination opportunities among industrial facilities. FaST achieves this potential coordination through a data base with facility profiles; those profiles can be used to identify possible facility linkages. There are 13 facility profiles under development, including organic chemical facilities, paint manufacturers, steel manufacturing, coal-powered electric utility, and composting facilities.

Forecasting Travel Patterns

FHWA's **Spreadsheet Model for Induced Travel Estimation (SMITE)** (http://www.fhwa.dot.gov//////steam/smite.htm) is a Lotus 123 spreadsheet model that applies the principles of economic analysis to evaluate highway capacity expansion in an urban setting, taking into account new travel that may be induced by highway expansion over and above that which is simply diverted from other regional highways. This model is useful for sketch planning level of analysis, especially in cases where four-step urban travel models are either unavailable or are unable to forecast the full induced demand effects. The SMITE spreadsheet can be used to provide useful information to assist policy makers in evaluating proposals for specific additions to highway capacity for corridor studies.

Geographic/Demographic Reference Tools

HUD's **Community 2020** software Version 2.0 (http://www.hud.gov/nofa/suprnofa/sprprt3b.cfm) is a GIS-based software program packaged with geographic and demographic data. Community 2020 includes geographic, demographic, and HUD program data with full-capacity mapping functions. The maps display housing conditions, economic indicators, income statistics, and population characteristics, as well as HUD-funded project locations. Users can zoom into a single block or view county-wide. Community 2020 can read text files, dBASE files, and other common data sources; the software package can also be modified to incorporate environmental or other social characteristics (e.g., crime rates). Scenario capabilities are unlikely without modification of the program, although Community 2020 could provide a basis of information to build upon. The data requirements are modest, in that Community 2020 already incorporates several social data sets (e.g., housing and census data). It is compatible with LandView III, EPA's geographic reference tool.

LandView III (http://www.epa.gov/swerosps/bf/lvinfo.htm) (http://cdserver.er.usgs.gov/lviii.htm) is EPA's electronic geographic reference tool. Developed in conjunction with the U.S. Bureau of the Census, this is its third-generation version. Landview III displays roads, rivers, and railroads; jurisdictional and statistical boundaries; EPA-regulated sites; and key geographic features provided by the U.S. Geological Survey and other federal agencies. It is distributed on a CD-ROM. It can be used to access 1990 census data; create a geographic map showing census data, hazardous waste sites, religious institutions, and schools; and estimate demographic characteristics within a radius from a given point. It also has search mechanisms.

Green Development Tools

The **Green Developments CD-ROM** (http://rmi.org/store/p385pid959.asp) is an interactive CD-ROM that fully describes an exciting new field in which environmental considerations are viewed as opportunities to create better buildings and communities by working with the environmental instead of against it. It features 400 visuals; resource details, including financial details; and web links to key related sites. You hear the architects talking about their designs, see how the buildings have taken shape, and listen to residents talking about their neighborhoods while viewing them.

Forecasting Accessibility

Method 1. Regional Accessibility

At the regional level, accessibility can most easily be measured using data from a regional travel demand model. Various measures of accessibility can be derived based on the number of jobs (or other opportunities) accessible within X minutes of the average person living in the region, or the number of residents accessible within X minutes of a typical employment site. The data required to compute this measure include population and employment by TAZ and zone-to-zone travel times. Accessibility can also be distinguished by mode of travel, by the median income of the TAZ of residence, or along other dimensions. Differences in accessibility by population subgroup can be compared among transportation alternatives to measure relative benefits.

The use of regional accessibility measures is demonstrated in the Montgomery County, San Francisco Bay Area, and Tren Urbano case studies. The San Francisco case study also includes an appendix that illustrates the use of occupational matching. Occupational matching is a refinement of the population-to-employment accessibility measure to include consideration of compatibility between the occupations of residents and the types of nearby employment. Rood (1997) describes a Local Index of Transit Accessibility (LITA), which compares zone-to- zone transit versus automobile travel times, weighted by overall trip volumes between zones. LITA utilizes data from an MPO's regional transportation model. If these data are not available, an alternative index is proposed which reflects qualities of the transit service being provided to a geographic area, based on transit operator data.

Method 2. Access to Transit

Access to transit is a mode-specific component of regional accessibility. It can serve as an indicator of the availability of modal alternatives, particularly to transportation-disadvantaged populations. Measures of transit accessibility can also indicate the extent to which land use-transportation patterns make alternatives to automobile travel feasible.

Measurements of access to transit generally rely on GIS to analyze the spatial relationship between transit stops or routes and population and employment. A basic measure of transit access is the number or percentage of people or employment sites within a reasonable walking distance (one-quarter to one-half mile) of a transit stop. This measure can be calculated in approximate terms by drawing a buffer around transit lines or stations and overlaying this buffer with TAZ-level population and employment data. More precise methods of transit station area analysis have recently been developed that utilize street network data and/or parcel-level land use data. Network data can be used to identify the actual street network within one-half mile walking distance of transit stations, while parcel data can be used to identify the number of dwelling units or square footage of development that can be reached within this distance. Examples are provided in the Orange County and Tren Urbano case studies. Jasciewicz and Russ (1998) provide an additional example of this type of analysis for light rail transit planning.

Transit access is most meaningful when combined with a level of service and/or accessibility measure. Transit level of service depends on a variety of factors including peak and off-peak headways, hours of service, and the coverage of the system. A detailed transit network in a regional travel model can provide a starting point for estimating transit levels of service between zones, as well as accessibility (i.e., to jobs) by transit. The addition of micro-level analyses such as those detailed above can help refine the analysis by providing a more precise estimate of population or employment convenient to transit.

Forecasting Effects on Sensitive Habitat and Wetlands

Impacts of transportation facilities on sensitive habitats and natural areas are typically addressed at the project level, for example, through the National Environmental Policy Act (NEPA) process which requires the development of an Environmental Impact Statement for major projects. Responses may include choosing an alternative that minimizes impacts on sensitive areas, or developing mitigation measures such as wildlife crossings or wetlands replacement. At the local level, sensitive areas may be set aside from development, for example, through restrictions on the filling of wetlands or designation as natural reserves.

At the same time, awareness is increasing of the need to consider habitat and open space preservation from a broader, regional perspective. Ecological systems do not adhere to city or county boundaries. Similarly, transportation and land use decisions have implications for development that cross jurisdictional lines.

A typical approach to incorporating sensitive habitat and open space considerations into regional transportation planning might include the following steps:

1. Identify areas that are important to preserve. Wetlands and riparian areas can be readily identified using existing USGS databases. Delineation of other areas of sensitive habitat is more complex process; some approaches are described below.
2. Analyze transportation alternatives to determine their respective impacts on these areas. Amount of wetlands destroyed is a basic measure. Measures can also be developed of fragmentation of contiguous natural areas.
3. The impacts measured in step (2) also should include secondary impacts - i.e., those resulting from shifts in land development patterns following the transportation investment. This step requires some form of land use modeling (see "land development impacts.")
4. Select alternative(s) that minimize impacts. This is part of a process of trading off all the various benefits and impacts of each alternative.
5. Develop mitigation measures to minimize the impacts of the selected alternatives. The mitigation measures may include local land use controls as well as modifications to the design of the transportation facilities.

The appropriate and available methods vary according to the type of impact being measured. These are discussed under the following categories: (1) Methods to quantify wetlands loss; and (2) Ecosystem and biodiversity analysis methods to identify and define sensitive habitats.

Wetlands

White applied a probabilistic analysis to estimate the wetland impacts of an expressway. (Louis Berger, 1998) The **Hydrogeomorphic Wetlands System**, developed by the Army Corps of Engineers, is a descriptive model to evaluate the functional aspects of wetlands. It can generate data to assist in determining highway alignments and conducting land use planning. The **Watershed Planning System** (WPS), developed by the Maryland Office of Planning, is a geographically-based decision support system that examines the effects of land use policies and development on nonpoint source pollution. As an intermediate step, it estimates impacts on wetlands of land transformation from development.

Biodiversity/Ecosystems

General State Analysis is a method of discussing and tabulating key biodiversity issues (wetlands, endangered species, etc.) in a matrix fashion. General State Analysis requires a relatively low level of effort and is commonly applied in NEPA studies (Bardman). The **Habitat Evaluations Procedure**, developed by the U.S. Fish and Wildlife Service in 1976, is a widely used habitat assessment methodology (Whitlock, 1994). It requires the development of habitat suitability indices for individual species. **Gap Analysis** combines habitat evaluation data with land management information to assist in land use and conservation planning to maintain critical habitats. Gap Analysis is generally performed at a regional or state level and requires a significant amount of effort to apply. It has recently been tested at the county level in Spokane, Washington (Stevenson, 1998). The focus of Gap Analysis is on the loss and fragmentation of natural landscapes as the principal reason for loss of biodiversity, in contrast with a species-by-species approach to the loss of biodiversity.

The **Habitat Evaluation Model** is a predictive tool to determine habitat value of lands within a region based on various habitat quality parameters. The San Diego Association of Governments (SANDAG) applied the Habitat Evaluation Model in a county-wide effort to identify areas of critical habitat and develop strategies to preserve these areas. SANDAG subsequently used GIS to overlay habitat maps with proposed transportation facilities. The overlay process was used to identify routes that minimized disruption to the identified areas. The approach is documented in *Transportation Case Studies in GIS: Case Study #1* (FHWA, 1999). **Multiscale Biodiversity Assessment** is a combination of ecological models at different scales to predict which species and habitats will be most stressed as a result of future development patterns. This method has been applied on a research basis in San Jose, California (Cogan, 1997) in conjunction with land use forecasts from the California Urban Futures Model (Landis, 1995).

Efforts are currently underway to develop an ecological network model for the southeastern U.S. The project involves evaluating and mapping high-quality ecological areas, identifying ecological "hubs," and developing a potential ecological "network" with corridors or linkages between hubs. Data and methods from this project are being considered for use in transportation and land use planning in the Atlanta, Georgia region (EPA, 2000).

CITYgreen (http://www.americanforests.org/garden/trees_cities_sprawl/citygreen/) is a Windows-based software package for ArcView, a desktop GIS. CITYgreen's purpose is to map urban ecology and measure the economic benefit of trees, soils, and other natural resources in the community development process. It allows users to create ecological maps, conduct technical analysis of the ecology, summarize results, and create graphic presentation materials. CITYgreen allows users to analyze storm water, summer energy savings, carbon storage and sequestration, air quality, and urban wildlife. Its intended users are those groups primarily concerned with the role of trees in soil erosion, storm water management, and air quality. Developers, local government engineers, and urban foresters are targeted users of CITYgreen. The software package works at the local level: It was demonstrated on a half-acre lot in a subdivision. The software has scenario capabilities; it can, for example, quantify the effects of cutting down trees versus planting different types of trees. Data requirements are moderate to significant, in that the software requires digital ortho-photography.

Forecasting Effects on Water Quality

While point source pollution (e.g., from industrial discharge pipes) has been significantly reduced over the past three decades, nonpoint source pollution has been much harder to control. Urban runoff - from roads, parking lots, buildings, and other impermeable surfaces - is a significant contributor to nonpoint pollution. Runoff may contain road salt, oil, fertilizers, pesticides, and other pollutants. It can also create high-sediment loadings in streams and rivers. High-sediment loadings can also result from erosion during construction activities.

The primary determinant of urban runoff is the proportion of ground cover that is impervious and does not allow rainwater to soak into the soil. As the proportion of impervious surface increases, the velocity and volume of runoff increases; flooding, erosion, and pollutant loads in receiving waters increase; groundwater recharge and water tables decline; stream beds and flows are altered; and aquatic habitat is impaired. The relationship between impervious cover and watershed degradation is not necessarily linear. Stream degradation occurs as impervious cover exceeds 10 percent, which can happen at residential densities of one unit per acre or less. At 30 percent cover, a watershed may be considered generally degraded. Industrial, commercial, and shopping center development can bring 75 to 95 percent imperviousness. (Benfield, Raimi, and Chen, 1999)

The percentage of impervious cover can be used as a proxy for water quality impacts associated with various types of development. Generic estimates of the percentage of impervious cover according to type and density of development have been developed for use in various models. A site-specific assessment can produce more refined estimates based on site plans showing street patterns, driveways and parking lots, building footprints, etc. The modeling of actual water quality impacts requires a more extensive hydrological model to translate runoff into sediment, nutrient, and pollutant loadings and other impacts.

Models that can be used to assess the water quality impacts of transportation and land development include:

The **INDEX** Model (http://www.crit.com/), a GIS-based decision support tool developed by Criterion Planners/Engineers. INDEX is a customized model that takes input files such as site or neighborhood plans and calculates a variety of measures. It is a framework model that is customized for each application according to indicators and functions selected by local stakeholders. Its main functions usually include data management, public information, scenario analysis, and indicator tracking. The scope of indicator measurements normally includes land-use, housing, employment, transportation, infrastructure, and the natural environment. With an alternate case scenario, a community can evaluate alternative community plans. After a base case has been loaded into the model, "what if" questions can be asked and INDEX automatically recalculates the measures of interest. Customizations are developed in either ArcView or MapObjects, and are licensed to the client organization for subsequent local use.
A version of this model, **Smart Growth INDEX**, is currently being developed to integrate transportation and land use modeling at a sketch-planning level.

The City of Seattle, Washington, in partnership with Roy F. Weston, Inc., successfully managed the development of a city wide geographic information system (GIS) that includes public land survey, legal lots and rights-of-way, parcels, street centerlines, water facilities, electrical facilities, shorelines, digital elevation models, and municipal boundaries. Weston has developed a water main replacement application that significantly advances the state-of-the-art determination of replacement priorities based on a wealth of input data. Rather than simply following canned replacement formulas, this application will incorporate statistical models based on Seattle's unique system history and characteristics. This new program is called **"PIPES" Pipe Evaluation System Application**. It will provide predictive and subjective models that will address water main deterioration, vulnerability, and criticality analysis. This will lead to greater effectiveness in the decisions regarding which water main projects should be funded.

Water Evaluation and Planning (WEAP) (http://www.seib.org/weap/index.html), a PC-based water planning tool. Operating on the basic principle of water balance accounting, WEAP is applicable to municipal and agricultural systems, single subbasins or complex river systems. Moreover, WEAP can address an immense range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project benefit-cost analyses.

Hydrologic Models. These may be developed at the watershed or small-area scale, and are frequently complicated and data-intensive. An example of a hydrologic model is **HSPF** (http://www.scisoftware.com/products/hspf_model_overview/hspf_model_overview.html). HSPF uses land surface characteristics such as land-use patterns and land management practices to simulate the processes that occur in a watershed. The **Watershed Planning System** (WPS) (http://www.epa.gov/OWOW/watershed/Proceed/ weller.html), developed by the Maryland Office of Planning, is a geographically-based decision support system that examines the effects of land use policies and development on nonpoint source pollution. The WPS does not model detailed hydrological processes, but it accounts for major factors that are not accounted for in hydrological models, such as subsurface flow and groundwater through riparian areas. The Office of Planning is currently working to integrate this model with the prediction of land use impacts based on transportation accessibility. If successful, this will provide a modeling link from transportation investments and policies to water quality impacts.

Forecasting Historical and Archeological Impacts and Community Impacts; Visualization Tools

Federal law mandates that federal agencies must consider the impacts of their projects to historic properties, including archaeological sites. Like wetland and sensitive habitat impacts, historical and archeological impacts traditionally have been considered in project-level planning rather than regional planning. At the state or regional level, however, GIS tools are increasingly being applied to inventory historical and archeological sites and to use this information in the siting and design of transportation investments.

If sites of archeological importance can be identified at a regional level, projects can be routed to avoid these sites, or excavations can be performed in advance of the project. Frequently, however, sites of archeological importance are not discovered until digging for the project has commenced. At this point in the project, delays, or modifications to the project can result in significant additional expenses. The identification of other historical sites can also be difficult. Historic resources can include entire districts or areas as well as individual sites. The extent to which specific sites or districts are worthy of historical protection is often open to question. Also, some areas with potential historical significance may not have been explicitly identified, or a decision has not been made on the extent to which they should be protected.

The following examples illustrate the use of GIS in identifying sites of archeological and/or historical significance: The Minnesota DOT has developed a statewide GIS-based model, known as **Mn/Model**, to predict the probability of archeological impacts from highway projects. The model uses environmental characteristics of known archaeological sites (e.g., proximity to a river or topography) to predict other sites where similar combinations of resources occur. Mn/Model will be used as a planning tool by Mn/DOT and other agencies, allowing planners to avoid areas of high potential for sites. If avoidance is not possible it will allow for more efficient and cost-effective survey efforts by determining locations for intensive survey and areas where no survey may be required at all. The North Carolina DOT has developed a statewide GIS system for the analysis of environmental impacts in project planning. This system allows planners to overlay the proposed project on designated historic sites and districts, wetlands, and other layers of information. Aerial photographs provide a base. The system provides a centralized repository of data on designated historical sites to assist in planning. NCDOT's system and its uses are documented in more detail in FHWA's *Transportation Case Studies in GIS* (FHWA, 1999).

Community Impacts/Visualization Tools

Other community impacts, aside from those addressed above such as noise and air pollution, may include the creation of barriers that restrict physical movement within a community, displacement of residents or businesses, or undesirable aesthetic impacts resulting from transportation facilities. These impacts are typically addressed in transportation planning through the public involvement process. A variety of public involvement techniques are available to elicit feedback on potential impacts, and to help community members identify alternatives with the least negative or the greatest positive impact. Newly-emerging tools such as computer-aided visualization techniques can assist in this process.

The **Community Image Survey** (http://www.lgc.org/clc/cis.html) is a tool for educating and involving community members in land use planning. The Survey consists of 40 slides of design characteristics that are presented for review at a public meeting or workshop organized to discuss some aspect of the land use and transportation planning process.

IPIX (http://www.ipix.com) is a visualization tool that can be used to generate pictures of images of design scenarios. IPIX can generate images by fusing photos, allowing communities to visualize the effect of proposed development options. IPIX images can be integrated into web sites.

The **Environmental Simulation Center** (http://www.newschool.edu/academic/gsmup/programs.htm#esc) assists architects, community planners, government agencies and preservationists in employing computer modeling techniques to analyze the physical and visual impact of proposed projects. The Center is a program of the Graduate School of Management and Urban Policy at the New School for Social Research, New York, New York.

Forecasting Effects on Air Quality

Emissions

Key emissions include criteria pollutants and precursors (Volatile Organic Compounds, Carbon Monoxide, Nitrogen Oxide, Particulate Matter, and Sulphur Dioxide); toxics; and greenhouse gases, especially CO2. Emissions are an intermediate impact. Impacts of ultimate concern include the level of population exposure to unhealthful levels of criteria pollutants, as well as contributions to acidic precipitation or greenhouse gas effects.

Method 1: Heuristics

Heuristic methods involve the multiplication of average emission rates by vehicle-miles traveled (VMT), by vehicle type. This approach can be taken to estimate criteria pollutants or CO2 emissions from motor vehicles when a detailed analysis is not required. Emission rates can be obtained from the output of emission factor models applied for other purposes.

Method 2: Emission Factor Models

Emission factor models are used to develop emission rates (grams of pollutant per mile of travel or start) for a variety of pollutants. These are estimated for an average vehicle in the vehicle fleet, based on a variety of data on the vehicle fleet characteristics, temperatures, speeds, and other factors that influence emissions. Commonly used emission factor models the U.S. EPA's **MOBILE** model (http://www.epa.gov/otaq/m5.htm) and the California Air Resources Board's **MVEI** model (http://www.arb.ca.gov/msei/mvei/mveicms.htm). MOBILE5 and MVEI can estimate emissions of hydrocarbons, NOx, CO, and CO2. A new version of MOBILE, MOBILE6, will be released in early 2001 to replace the existing MOBILE5 model. Outputs of emission factor models are then multiplied by VMT by speed, vehicle type, temperature, and/or other parameters to estimate overall vehicle fleet emissions. Emission factor models are widely applied in the U.S. for regulatory purposes.

If transportation inputs can be developed spatially (e.g., by traffic analysis zone), emission factors can be applied to estimate total emissions on a spatial basis. Emissions by location can then be used as inputs to regional airshed models that simulate the reaction of primary pollutants to form secondary pollutants (such as ozone), as well as the movement of these pollutants.

Method 3: Advanced Emission Models

Considerable research has been undertaken recently to improve the state of practice in emissions modeling. In addition to continuing advances by EPA and CARB to the MOBILE and MVEI models, notable developments include:

The **MEASURE** model (http://www.epa.gov/crb/apb/mobile.htm) developed at the Georgia Institute of Technology. This model interfaces with travel demand model output in a GIS environment to determine emissions on a spatial basis. A further refinement is that socioeconomic data are used to estimate differences in the vehicle fleet by geographic area. This is significant because a neighborhood with older vehicles may have higher levels of emissions locally, which may in turn affect patterns of regional pollutants such as ozone. The MEASURE model has been applied in the Atlanta region.

The **Comprehensive Modal Emissions Model** (http://www.cert.ucr.edu/groups/tsr/em.html) developed for NCHRP Project 25-11 at the University of California - Riverside. These models refine the emissions estimation process by associating emissions with vehicle operating mode characteristics, such as speed/ acceleration profiles, and/or with physical characteristics such as power-to-weight ratio and transmission type. Modal and physical models have the potential for use in conjunction with traffic simulation models to develop more refined emissions estimates, and also to better estimate the effects of actions such as traffic flow improvement on emissions.

Air Quality

The Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards for pollutants considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. EPA has established ambient standards for six "criteria" pollutants including carbon monoxide (CO), nitrogen dioxide (NO2), ozone (O3), lead (Pb), particulates less than 10 micrometers (PM10) and less than 2.5 micrometers (PM2.5), and sulfur dioxide (SO2).

Assessing the impacts of transportation activity on air quality requires translating emissions by location into criteria pollutants by location. Air quality models have been developed at the micro-scale, to examine air quality impacts adjacent to roadway segments or intersections, as well as at the regional scale, to examine the regionwide formation and transport of pollutants. Some emissions from vehicle exhaust, such as CO, are also criteria pollutants. Others, such as volatile organic compounds (VOC) and oxides of nitrogen (NOx), react to form criteria pollutants such as ozone.

For criteria pollutants from exhaust, it may be sufficient to model only the dispersion of pollutants from the source of emissions. For secondary pollutants such as ozone, it is also necessary to model reactions that take place in the atmosphere that lead to formation of the pollutant. In either case, modeling of air quality requires, at a minimum:

- Knowledge of the spatial and temporal distribution of emissions;
- Assumptions about meteorological conditions, such as wind speed and direction, temperature, humidity, and sunlight; and
- Assumptions about the locations of "receptors," or the points at which air quality is being modeled.

A final step, which is usually not performed in air quality modeling, is to overlay the distribution of air pollutant concentrations with the distribution of human activity, to estimate the actual exposure of people to pollution.

Method 1: Micro-scale Transport/Diffusion Models

Micro-scale transport/diffusion models, such as **CALINE** (http://www.ess.co.at/GAIA/models/caline.htm) or **CAL3QHC** (http://www.eos.ncsu.edu/eos/info/ce400_info/www2/cal3qhc.html), are commonly used to assess the air quality impacts of actions such as intersection improvements or developments that increase traffic at particular intersections. These models require data on the traffic patterns on the roadway, wind speed and direction for typical meteorological conditions, and the geometry of the roadways and receptors. The models produce concentrations of pollutants by distance from the roadway. Micro-scale models are typically applied for CO, but may also be applied for NO2 and PM.

Method 2: Regional Transport/Diffusion Models

Regional **Gaussian dispersion models** simulate the transport of pollutants through a region, usually across a two-dimensional grid. As with micro-scale models, wind speed and direction for typical meteorological conditions are used in conjunction with emissions by spatial location (generally by grid cell) to estimate concentrations in each grid cell. These models can be overlaid with population data to estimate exposure to pollutants such as NO2 and PM. Gaussian dispersion models are much simpler to apply than regional airshed models, which also model reactions and may be three-dimensional. However, they cannot be used to determine exposure to pollutants, especially ozone, that are formed mainly through chemical reactions.

The **Envision Utah** and **SPARTACUS** case studies both provide examples of the application of Gaussian dispersion models at the regional level:

The Envision Utah project included the development of a model known as **QMOD** for northern Utah. The first component of QMOD is a model that simulates wind speed and direction over the area on an hourly basis. The second component is the capability to spatially disaggregate emissions from county-wide totals to an overlay of a regularly spaced (four-kilometer) grid. The model was used to develop metrics of population exposure to CO, PM, and ozone precursors. In the SPARTACUS project in Europe, transportation-related emissions data are decomposed within a GIS 100-meter grid cell environment to pinpoint PM, NO2, and CO emissions spatially. A dispersion model is then applied to track pollutants and to measure their coincidence with population. Exposure to emissions is also measured by socioeconomic group to develop indicators of equity.

Method 3: Regional Airshed Models

Regional airshed models also operate by taking inputs of typical meteorological conditions and emissions by grid cell, and simulating the movement of pollutants among grid cells. In addition, the models consider reactions between compounds that depend upon meteorological conditions. They are typically applied in the U.S. for regulatory modeling purposes, to simulate conditions under which ozone exceedances are likely to occur. The **Urban Airshed Model** (http://www.ccl.rutgers.edu/~ssi/thesis/thesis-node55.html) is a commonly used model in the U.S.

Regional airshed models are data-intensive and time-consuming to develop and calibrate. Also, the relationships being modeled are quite complex and so current models have some limitations. As a result, regional airshed models are not normally used in conjunction with transportation models to model the impacts of alternative regional transportation investments or policies. With advances in computing power, scientific knowledge, and GIS data management techniques, the direct use of these models in transportation planning could become more common in the future. The **MODELS-3** project (http://www. epa. gov/HPCC/models3. html) being undertaken by the EPA is one effort to advance the state of practice in this area.

Forecasting Noise Levels

Noise can be defined as unwanted or detrimental sound. Traffic noise is a function of the volume, speed, and composition of traffic. The level of noise at any given point also depends on the distance from the source and physical objects that may absorb or reflect sound waves. Sound is measured in decibels (dB), which have a logarithmic scale so that an increase of 10 dB sounds twice as loud. When measuring noise, an adjustment factor is typically applied to weight high-pitched and low-pitched sounds to approximate human hearing of these sounds. The resulting measure is known as "A-weighted decibels" (dBA).

Noise from traffic can be disruptive to people both outdoors and indoors by causing sleep disturbance, communication interference, and general annoyance. Tolerance for noise can vary greatly from person to person. Communities often set acceptable noise thresholds based on the time of day and adjacent land uses. Common noise standards include L10, the noise level in dBA exceeded 10 percent of the time during specified hours; L50, the noise level exceeded 50 percent of the time; and Leq, a scale that converts a varying noise level to an equivalent constant noise level.

From a regional planning perspective, the exposure of population to traffic noise can be influenced by the location of major roadways; automobile and truck traffic volumes; the design of neighborhoods and buildings; and attenuation measures such as noise wall construction.

Method 1: Traffic Noise Models

FHWA's **Traffic Noise Prediction Model** and **STAMINA** software were originally developed in 1977. A version of STAMINA, updated by the Minnesota DOT and known as **MINNOISE**, was applied in the Waterloo, Iowa case study. This model was used to compute Leq, L10, and L50 noise levels based on traffic volume, mix, and speed. Noise contours were plotted using a GIS and overlaid on low-income and minority population data to estimate exposure by population group. The Sacramento Council of Governments (SACOG) conducted a regional noise assessment for the Environmental Impact Review of its 1999 Metropolitan Transportation Plan (MTP). SACOG employed the FHWA Highway Traffic Noise Prediction Model to conduct a cumulative noise analysis of the regional highway system. Inputs to the model included average daily traffic volume (ADT), the day/night traffic distribution, medium and heavy truck percentages, and vehicle speed. Network segments with similar traffic characteristics were aggregated, and noise levels 150 feet from the centerline were predicted. Tables and maps were then used to show the number of roadway segments in which traffic noise levels for the Proposed Plan Option were predicted to increase and decrease significantly, relative to the year 2022 No Project Plan Option.

FHWA developed an updated **Traffic Noise Model** (TNM) (http://mctrans.ce.ufl.edu/featured/trafficNoise/) in 1998 to replace the Traffic Noise Prediction Model. In addition to the model software, FHWA has developed lookup tables from the TNM model for use in sketch-planning and screening applications. The lookup tables, which require only basic traffic and roadway geometry data, were developed by running the TNM under a variety of inputs. The TNM lookup tables are available at no charge from FHWA.

In the SPARTACUS project in Europe, transportation data are decomposed within a GIS 100-meter grid cell environment to pinpoint emissions on a spatial basis. A noise propagation model is then used to estimate noise levels by grid cell. These values are overlaid with population data to estimate exposure to noise by socioeconomic group. Noise propagation is estimated as a function of the type and density of development as well as the distance from a roadway.

Method 2: Noise Valuation

The **Surface Transportation Efficiency Model (STEAM)** (http://www.fhwa. dot.gov/steam/index.htm) (see also p.29), is a model developed by FHWA to estimate user benefits and costs of transportation projects, based on trip tables and networks from four-step travel demand models. STEAM includes default values to monetize noise impacts, based on VMT by vehicle type.

Forecasting Energy Consumption

Energy consumption from transportation is primarily a function of VMT and fuel efficiency by vehicle type. Other parameters, such as speed and acceleration, also influence energy consumption. However, their effect on regional transportation energy use is not usually considered because of the extra data requirements.

In addition to the transportation system, land use planning and urban design affect energy use. The density, mix, and arrangement of land uses in a community heavily influence the amount and mode of travel and, therefore, transportation energy use. These same urban characteristics also affect the amount of energy needed to heat and cool buildings and to build and operate community infrastructure. The relationship of energy consumption to land development patterns can be estimated by relating development by type and density to energy use. The more detail is available on the specific design characteristics of development (e.g., size of buildings, solar orientation, relative siting, topography), the more accurate the measurement of energy consumption.

Energy consumption can be important because of the negative environmental impacts associated with many types of energy use, as well as the economic and national security implications of dependence on foreign energy. In the case of transportation vehicles, energy consumption is almost entirely from petroleum-based fuels, of which a substantial proportion are from foreign oil reserves. Consumption of petroleum fuels is also directly related to emissions of carbon dioxide, a greenhouse gas.

Method 1: Heuristics

This is a simple approach which multiplies VMT by fuel consumption rates to obtain total energy use. VMT for different transportation and/or land use scenarios may be obtained from the regional travel model or from other analysis methods. VMT should be identified for major classes of vehicles, including light-duty vehicles, trucks, and transit vehicles, to reflect the full energy impacts of each scenario.

Method 2: Custom Models

A handful of custom models have been developed to assist state and local governments in identifying the energy impacts of different transportation and land use scenarios. These include:

The **Tool for Evaluating Neighborhood Sustainability**, developed for the Canadian Mortgage and Housing Corporation to evaluate greenhouse gas emissions for urban travel in different types of neighborhoods in Toronto. The tool is based on a multivariate regression model that predicts travel and greenhouse gas emissions on the basis of neighborhood attributes, sociodemographic data, and locational characteristics (e.g., distance from the CBD).

Planning for Community Energy, Economic and Environmental Sustainability (PLACE3S) (http://www.sustainable.doe.gov/articles/place3s. shtml) , a land use and urban design method created to help communities understand how their growth and development decisions affect energy consumption and other impacts. It integrates public participation, planning, design, and quantitative measurement in a five-step process appropriate for regional and neighborhood- scale assessments. PLACE3S quantifies energy, economic, and environmental effects of alternative plans. Thus, it appears to meet the criteria of being appropriate for the local level, capable of building scenarios, and considering the interaction among multiple dimensions. Running PLACE3S requires running INDEX (see below). The PLACE3S methodology has been used by the San Diego Association of Governments (SANDAG) to assess the energy efficiency of the region's growth management strategy alternatives. The study used an integrated GIS land-use and transportation model to permit easy alteration of land use designations and to test how travel demand changes as land use changes. PLACE3S was also used for a similar exercise as part of regional transportation planning by the Lane County Council of Governments (Eugene-Springfield area) in Oregon.

INDEX (http://www.crit.com/) (see also p.11), a GIS-based model that computes a variety of indicators of development patterns, including energy use. Like PLACE3S, INDEX is capable of estimating energy consumption from development patterns as well as from transportation infrastructure and travel.

The **Long-range Energy Alternatives Planning (LEAP)** system (http://www.seib.org/leap/index.html), an accounting framework for energy planning, with environmentally sound energy strategies as a component to the software. At the heart of LEAP is the process of scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions. Using LEAP, scenarios can be built and then compared to assess their energy requirements, social costs and benefits and environmental impacts.

Forecasting Economic Development

Method 1. Econometric Models

Statistical methods such as multiple regression analysis are first used on time series and cross-sectional data to show the impact of investment on highways and fixed-guideway transit lines on regional job creation, income, and property values. The "elasticities" or "impact factors" found from those regressions are then applied to estimate the expected future impact of highways and transit investments on growth in those regions.

A study for the proposed I-73 in Virginia (Gillespie, 1995) forecast changes in total economic activity based on highway capital expenditures. Coefficients relating investment to economic activity were taken from national studies relating economic activity to highway capital stock. The analysis was at a broad level that did not distinguish how the economic growth would be affected by differences in the highway location and level of use. Regression models have been applied in a number of studies to estimate the property value impacts of urban transit systems or highways. These models can be used to infer impacts of future transportation investments of a similar nature. Weinberger (2000) describes a study in the San Jose metropolitan area of California in which regression models were developed for an existing light rail system to address the potential property value impacts of planned extensions.

Method 2. Input-Output Models

Input-Output (I-O) models contain information on inter-industry relationships, including "multipliers" that are used to forecast impacts as the dollars spent on a transportation investment ripple through the economy. I-O models are well suited for measuring the impacts of expenditures for the construction and operation of transportation facilities. They can also be used with exogenous inputs to calculate how changes in accessibility and transportation costs induce changes in levels of economic activity. For example, if a highway's impact on tourism can be translated into expenditures per new tourist, these expenditures can be fed through an I-O model to measure impacts on the regional economy.

The following examples illustrate the application of I-O models to transportation investments:

Maryland DOT performed a study of the statewide economic growth impacts of statewide highway programs (RESI, 1998). Researchers first applied a statewide I-O model to calculate the total economic activity supported by highway spending and subsequent purchases of labor, goods, and services. Using the results from the I-O modeling, the study then assessed how the state's economy would differ with and without the highway investment. The Maryland study also employed an econometric model to account for changes in business operating costs over time, and industry "cost functions" to capture business productivity growth attributable to highway investment. Similar studies have been done for Texas and Kansas. Batey, Madden, and Scholefield (1992) utilize an input-output model to assess the regional impacts of an airport expansion in the United Kingdom. Economic inputs include expenditures on construction and operation, income from employment, local expenditures from additional passengers, and relocation of airline headquarters.

Method 3. Macroeconomic and Demographic Simulation Models

Macroeconomic simulation models are integrated modeling systems that include both an I-O model and a production function. These model components are integrated, and allow for the researcher to calculate how changes in policy decisions will impact economic conditions. Unlike I-O models which are static and allow only a one-time snapshot of the impacts of a transportation investment, simulation models allow the researcher to track the regional economic impacts of an investment over time. Some models can also estimate how changes in business operating costs and household living costs affect regional business expansion and population growth.

The **REMI Model** (http://www.remi.com/html/product_info.html) , developed by Regional Economic Models, Inc., is a well-known simulation model that has been applied to a number of regional highway and transit investment scenarios. A REMI model includes 30 – 35 year economic histories, and 35-year forecasts of one or more regional economies and the U.S. REMI Policy Insight offers users a Windows/spreadsheet interface to change up to 6,000 variables, enabling them to test the impacts of policies and events on employment, wages, output, population, and hundreds of other measures. User benefits from each scenario, including time, operating cost, and accident cost savings, are entered as cost savings or productivity improvements to businesses. Construction and operating costs are entered as expenditures by business category. Specific applications include the evaluation of freight projects in Portland, Oregon and Columbus, Ohio; a comparison of regional highway versus transit investment plans in New York and Los Angeles; and evaluations of transit investments or disinvestments in Chicago, Philadelphia, and Rochester, NY; and evaluation of intercity highway corridor improvements in Wisconsin, Indiana, and Maine.

Method 4. Integrated Economic and Land Use Models

Some land use models contain economic relationships, such as input-output matrices, as part of their underlying foundation. These models are capable of measuring the three-way relationship among transportation, land use, and the economy. At the heart of the **MEPLAN** model (http://www.meap.co.uk/meap/ME&P. htm) , for example, are input-output relationships that specify each sector's consumption from other sectors as well as its consumption of land and generation of trips by type. These models are typically used to measure forecast the distribution of economic activity within a region. Compared to an economic simulation model such as REMI, they are much more limited in their economic detail, as their primary purpose is to forecast land use changes rather than overall regional economic effects.

Examples of applications include:

The land use models **MEPLAN** and **TRANUS** (http://www.modelistica.com/modelistica.html) have been applied in a number of metropolitan areas in the U.S. and Europe (see Sacramento and SPARTACUS case studies). The MEPLAN model has been used to forecast impacts of local projects on urban areas (such as improvements to the A7/A68 motorway in southeast Scotland), and broader regional impacts of larger projects (such as the Channel Tunnel). The local urban applications have typically featured small area zones and very limited industry detail, while the larger regional applications have typically featured broader zones and a greater level of industry detail. The **METROSIM** model is a custom model now being tested in New York metro area (Anas, 1999). It combines a market-oriented economic (labor market) model with a transportation and land use model. The model takes into account how transportation projects are affected by the locational pattern of demand for land uses, and also allows basic and service employment to respond to transportation changes through labor market and businesses location decisions.

The **TELUS** system was developed by the New Jersey Transportation Institute, Rutgers University, and the North New Jersey Transportation Planning Authority to help MPOs select projects for their TIPs (Transportation Improvement Plans). TELUS has three components: a) a data base with key information about projects; b) an I-O model for estimating jobs created and the income and tax impacts of projects; and c) a land use model for estimating property tax impacts. The research team used national inter-industry relationships as well as relationships developed from New Jersey bid sheets to develop impact factors and economic multipliers for the I-O model. Multipliers reflect the ratio of total/direct effects, and are expressed in terms of jobs (by industry), income, and GRP per million dollars of original investment.

Forecasting Fiscal Impacts

Method 1. Fiscal Accounting Systems

Fiscal accounting systems forecast how changes in population, employment, and income patterns will lead to changes in expenditures and revenues for government agencies. Expenditures typically include police, fire, schools, social services, utilities, etc., and revenues typically include various taxes and fees. Fiscal impact models normally focus on the effects of projects which are either very localized or very skewed in terms of the affected sectors of the economy. For instance, a new residential development or a new office park, either one made possible by transportation improvements, can lead to very different effects on school demands, property tax revenues and local service demands.

Guidebooks for fiscal impact analysis have been developed by the Urban Land Institute (Burchell, Listokin, et al., 1994) and the Center for Urban Policy Research at Rutgers University (Burchell, Listokin, and Dolphin, 1985). **FISCALS** is the second generation of Tischler & Associates' MUNIES software that was widely used in the 1980s. FISCALS is a family of software systems, each of which is custom designed for every community. Among its features ares the ability to project "lumpy" capital facilities, factor lag-lead time of construction, forecast associated operating expenses once the facility opens, and consider available and excess capacities. FISCALS operates in a spreadsheet environment and can be used with Microsoft Excel, Lotus 1-2-3 and Quattro Pro.

Method 2. Specialized Cost Models

Infrastructure cost models estimate the costs of infrastructure - roads, water, sewer, etc. - as a function of the characteristics of development. Types of infrastructure modeled include transportation (roads, sidewalks, transit), water and sewer, telecommunications, gas, and electric utilities. Specialized cost models may rely on some of the same data or cost functions as fiscal accounting systems. They differ in that their focus is on the total costs of infrastructure, rather than the cost and revenue impacts to specific government units. The models may also track the level at which costs are accrued (site developer, municipal service provider, or regional agency). Examples include:

The **Infrastructure Cost Assessment Model** developed as part of the **Envision Utah**. The model estimates infrastructure costs by density and by type of development (greenfield, infill, or redevelopment.)

The **Social Cost of Alternative Land Development Scenarios (SCALDS)** model (http://www.ota.fhwa.dot.gov/scalds/), developed by FHWA, estimates monetary and non-monetary roadway, water, and sewer costs, by development type and density, at the metropolitan scale. The full cost accounting framework uses average cost data, derived from a variety of national studies, as the default values for the calculation of costs. SCALDS in its present form is a series of interconnected EXCEL spreadsheets that estimate total costs for three accounting paths. The first cost estimation path focuses on physical development, including land consumption, existing and projected housing mix, regional employment, and local infrastructure capital and operating costs. The second accounting path estimates the annual peak and non-peak cost of travel on a passenger mile traveled (PMT) basis. The third path estimates non-dollar denominated costs such as air pollution and energy consumption.
estimates.

InfraCycle software (http://www.infracycle.com/products.html), developed for the Canada Mortgage and Housing Corporation and the Regional Municipality of Ottawa-Carleton, is a fiscal impact tool that calculates the life cycle cost of municipal infrastructure (fire, police, roadways, sidewalks, street light, park land, recreation facilities, storm water, sanitary sewers, garbage collection, transit, schools, school busing). Municipal revenues can be calculated from sources such as taxes, levies, development charges, application fees, etc. Revenues are compared to costs to determine if revenues will support costs. The software can be used for large or small projects. Silver City, New Mexico, for example, has acquired the software to assess the impact of a proposed 6,000-acre annexation. InfraCycle software is a fiscal impact model used to assess the implications of policy plans and development applications. It is designed for use by municipalities of all sizes and for projects of 2 acres to 10,000 acres. The software will be used by the town of Silver City, New Mexico to determine the impact of a 6,000-acre annexation proposal by a developer. The user will calculate the lifecycle cost of municipal infrastructure such as roads, sanitary sewers, storm sewers, streetlights, sidewalks, recreation facilities, garbage collection, schools, transit, and utilities. Revenues from municipal sources are calculated, revenues are compared to costs to determine if revenues will support costs.

Revenue forecasting and cost estimation models also have been designed specifically for transportation agencies for the purposes of financial planning. An example is the **System Cost and Revenue Estimation (SCARE)** model, a software package that will provide planners with tools for revenue forecasting, cost estimating, and program balancing. This software is currently being developed by FHWA.

Method 3. Simulation Models

Simulation models are integrated modeling systems that include an input-output (I-O) model to predict economic impacts of different policies, which in turn affect fiscal impacts. Simulation models include:

The **TELUS** system, developed by the New Jersey Transportation Institute, Rutgers University and the North New Jersey Transportation Planning Authority. TELUS is based on a database containing key information about transportation projects. It then estimates economic impacts through an I-O model as well as tax impacts on local governments. A land use modeling component is being developed to estimate the fiscal impacts of changes in land use induced by transportation investment.

The **REMI** simulation model (http://www.remi.com/html/product_info.html), primarily used for economic forecasting, also contains a fiscal element. Because of the regional level of analysis (county or greater), expenditures and revenues generally grow at the same rate. In fiscal analysis, REMI is primarily used as a driver for fiscal accounting systems (Method 1).

Forecasting the Distribution of Impacts Among Socioeconomic Groups or Geographic Areas

Methods for discussing impacts such as accessibility or environmental impacts are discussed under the relevant impact sections. The following section identifies three techniques that can be used to disaggregate these impacts among socioeconomic groups or geographic areas.

Method 1. Spatially Based Analysis

This method compares the distribution of impacts among spatial units such as traffic analysis zones (TAZs) or census tracts, which can be classified by characteristic (low-income, predominantly minority, etc.). A general procedure is as follows:

1. Classify the spatial units according to the characteristic(s) across which the impacts are to be compared. For example, identify TAZs corresponding to census tracts with greater than X percent population in poverty or racial minority population.
2. Identify the magnitude of transportation project impacts for each spatial unit. For example, measure the change in accessibility, total emissions, or the concentration of emissions for each TAZ in the analysis area.
3. Compare the magnitude of impacts among the population groups of interest. For example, compare the average change in accessibility as a result of the regional transportation plan for TAZs with a higher racial minority population with the average change for TAZs with a lower minority population.
4. If appropriate, apply statistical tests to determine whether differences between alternatives and/or population groups are statistically significant.

Examples of this type of approach include:

San Francisco Bay Area accessibility analysis: The accessibility of residents to employment was compared for "disadvantaged" and "non-disadvantaged" neighborhoods, under the Regional Transportation Plan versus the no-plan alternative. Accessibility was measured based on travel times from the regional travel model highway and transit networks and on forecast population and employment by TAZ. Statistical tests were applied to measure the significance of differences.

Tren Urbano analysis: Accessibility is compared by mode (automobile, rail transit, and bus) and across five income groups to help analyze the impacts of the Tren Urbano rail transit project. TAZs are grouped according to average income level. For each group, the average accessibility of residents to employment is calculated based on transportation network travel times. The approach described above can be facilitated or enhanced through the use of a GIS. For example, emissions and noise contours can be developed from the locations and characteristics of roads and traffic, and these contours can be overlaid on spatial units such as census block groups or tracks. Then, impacts can be compared according to the characteristics of the spatial units.

The **Surface Transportation Equity Assessment Model (STEAM)** (http://www.fhwa. dot.gov/steam/ index. htm) (see also p.29) is currently being modified by the Federal Highway Administration to assess benefits by zones. STEAM is a post-processor model that utilizes the output of four-step travel demand models and calculates various user benefits and externalities. Benefits and impacts will be assigned to TAZs or user-defined groups of TAZs to allow an analysis of the distribution of changes in impacts.

Method 2. Spatial Disaggregation

This approach is similar to Method 1, except that a GIS raster module is used to disaggregate socioeconomic data and impact data to grid cells. This allows impacts calculated for different types of spatial units to be more precisely overlaid on population data. For example, emissions from a transportation network can be assigned to the grid cells corresponding to the network, and then overlaid with population data that is assigned from the census tract level to each grid cell.

Examples of the use of spatial disaggregation to identify the incidence of air quality impacts are provided in the **SPARTACUS** case study and the **Envision Utah** case study. The SPARTACUS case study also illustrates the distribution of noise impacts by population and compares the overall incidence of negative impacts across three socioeconomic groups.

Method 3. Microsimulation

Microsimulation travel modeling techniques forecast travel by modeling a set of actual or synthetic individuals or households that represent the population. (A "synthetic" sample is composed of a hypothetical set of people or households with characteristics that as a whole match the overall population.) Full microsimulation of a population is yet to be commonly implemented in practice due to computational requirements. A variant known as "sample enumeration" has been applied successfully in a number of areas, however. Sample enumeration relies on the modeling of behavior for a representative sample of the population.

The benefit of this modeling approach for analyzing the distribution of impacts is that travel patterns, and therefore the travel benefits of transportation improvements, can be tracked across any population characteristic that is included in the sample of persons modeled. Historically, this has been done by income level, since income is commonly used to predict travel behavior. The characteristics of the sample can also be broadened to include race or other characteristics.

Some examples of the microsimulation approach include:

The **STEP model**, a sample enumeration-based travel forecasting approach. STEP has been applied in the San Francisco Bay Area in a number of studies, and has also been adopted for use in Los Angeles, Sacramento, Chicago, and Seattle. It has been used to analyze travel impacts of pricing scenarios by income group (EPA 1998), as well as for other purposes. A travel model is currently being developed for the City and County of San Francisco using a sample enumeration approach. The model is being developed specifically with the intent of tracking travel and benefits by race, income, and other characteristics (Cambridge Systematics, Inc., 2000).

The new generation of **activity-based travel models** (Engelke, 1997) also generally rely on sample enumeration, thus allowing benefits to be tracked by user characteristic. In an activity-based model, travel decisions become part of a broader activity scheduling process based on modeling the demand for activities rather than merely trips. An activity-based model was recently developed for the Portland, Oregon region and will be used in the future as their primary travel demand model (Bowman et al., 1998).

Forecasting Costs and Benefits

Method 1. Benefit-Cost Analysis Models

Benefit-cost models calculate user benefits and external costs for alternative transportation networks or projects and compare them with capital, operating, and maintenance costs. User benefits, including time, operating costs, and safety costs, are based on differences in travel patterns and transportation network characteristics. Some models also include valuations for externalities such as emissions, energy, and noise.

The **Surface Transportation Efficiency Model (STEAM)** (http://www.fhwa.dot.gov/steam/index. htm), is a model developed by FHWA to estimate user benefits, costs, and externalities of transportation projects, based on trip tables and networks from four-step travel demand models. STEAM calculates user benefits based on changes in consumer surplus for travelers at the link level. STEAM also estimates and monetizes externalities including emissions, energy consumption, and noise based either on default or user-input values. STEAM has been applied in New Jersey to estimate user benefits of Route 1 corridor improvements, and in the New York metropolitan area to analyze regional freight strategies.

The **ITS Deployment and Analysis System (IDAS)** (http://www.camsys.com/product_idas. htm) is a sketch-planning network model to analyze the travel impacts, user benefits, infrastructure costs, and other social benefits and costs of over 60 intelligent transportation system (ITS) strategies. IDAS utilizes local travel model network and trip table data and allows the user to apply ITS strategies at the network, link, or zone level. IDAS has been applied in a number of metropolitan areas including Cincinnati, Detroit, Miami, and Tucson.

Net_BC is a benefit-cost model that computes benefit-cost measures based on travel demand model assignments. Benefits include time savings, operating cost savings, and accident reductions. Net_BC has been applied in Indiana and other areas.

StratBENCOST (http://www.hlb-econ.com/web1/prod02.htm) is a benefit-cost model that computes benefit-cost measures based on user-input traffic characteristics, project costs, and growth factors. Impacts considered include time, operating, and safety cost savings; construction, operation, and maintenance costs; and emissions and social/neighborhood benefits. StratBENCOST was developed for the National Cooperative Highway Research Program (NCHRP).

Method 2. Life-Cycle Investment Models

These models are designed to compare alternative highway investment strategies by comparing user benefits with life-cycle capital, operating, and maintenance costs under different strategies. The models are commonly used to assess tradeoffs between system expansion and system preservation, as well as to evaluate the benefits of different overall levels of investment.

The **Highway Economic Requirements System (HERS)** (http://www.fhwa.dot.gov////////infrastructure/asstmgmt/hersfact.pdf) is a benefit-cost analysis system developed by the Federal Highway Administration. It is used to compare improvements to highway segments including resurfacing, reconstruction, widening, etc. While it has primarily been applied at a national level, the states of Oregon and Indiana have adopted it to analyze statewide investment strategies. These features have been adopted into a new state-level version of the software known as HERS/ST.

The **Highway Development and Management Tools (HDM-4)** model (http://hdm4.pi arc.org/main/home-e.htm) (http://mctrans.ce.ufl.edu/featured/hdm/) was developed by the World Bank. It estimates road user benefits, infrastructure costs, and externalities including accidents, energy, and emissions for alternative investment strategies. It can be applied at either the project or program level. Previous versions of the model have commonly been used internationally to evaluate tradeoffs between highway expansion and preservation.

Method 3. Other Cost-Benefit Analysis Methods

Other methods have been applied based in principles similar to those underlying the models in Method 1. However, these rely on some level of user programming of functions rather than coming as pre-packaged software.

A study was conducted in Seattle using a combination of the Puget Sound Regional Council's travel model and the STEP model to compare the social benefits and costs of highways, transit, and pricing at the regional level. The study included a sensitivity analysis of different assumptions, including assumptions regarding commercial vehicle travel (ECONorthwest, 1996). Contingent valuation (CV) is an economic method to estimate changes in total user benefits from shifts in travel demand and network characteristics. CV is a way of measuring "consumer surplus," as is done in the STEAM model. The Sacramento case study illustrates how CV can be calculated directly from travel model output, and how it can be used to compare alternatives based on the per-trip equivalent cost savings for the average user.

Least-cost planning is an approach toward determining transportation alternatives that minimize total social costs. It includes the application of benefit-cost techniques, in conjunction with the consideration of demand reduction and supply expansion projects on equal footing. The least-cost planning approach is described in ECONorthwest and Parsons Brinckerhoff (1995). An application of least-cost planning to the Seattle area is documented in Nelson and Shakow (1996).

REFERENCES – PUBLISHED CITATIONS/CONTACT AGENCIES

Methods, Models, and Software

Comprehensive Modal Emissions Model
University of California at Riverside
Prof. Matthew Barth
909-781-5782

DRAM/EMPAL
S.H. Putman Associates, Inc.
Stephen Putman
215-848-2385

FISCALS
Tischler & Associates
800-424-4318

FTIM
(Freight Transportation Investment Model)
Cambridge Systematics, Inc.
Lance Grenzeback
617-354-0167

Gap Analysis
United States Geological Survey

HDM-4
(Highway Development and Management Tools)
Information: World Bank, PIARC
Software: McTrans, University of Florida

HERS
(Highway Economic Requirements System)
Federal Highway Administration
Thomas Keane
202-366-9242

HLFM II+
AJH Associates
Alan J. Horowitz

HSPF watershed model
Scientific Software Group

Hydrogeomorphic Wetlands System

Army Corps of Engineers
Federal Highway Administration:
Paul Garnett
303-969-5772 x332

IDAS (ITS Deployment Analysis System)
Software: http://mctrans.ce.ufl.edu/
Information:
Cambridge Systematics, Inc:
Vassili Alexiadis
510-873-8700
Sofware:
McTrans, University of Florida

IMPLAN
Minnesota IMPLAN Group:
651-439-4421
info@implan.com

INDEX model
Criterion Planners/Engineers:
Eliot Allen
503-224-8606

InfraCycle software
InfraCycle Software Ltd.
888-836-1618
ray@infracycle.com

Land Transformation Model
Michigan State University:
Bryan Pijanowski
517-432-0039

MEASURE emissions model
Georgia Institute of Technology
Randall Guensler
404-894-0405

MEPLAN
Marcial Eschenique & Partners Ltd.
Marcial Eschenique
(0223) 840704

Mn/Model archeological model
Minnesota Department of Transportation:
Beth Hobbs
651-296-9243

Joe Hudak
651-296-6116

Net_BC
Bernardin, Lochmueller & Associates
Michael Grovak
765-463-0502

PLACE3S
United States Department of Energy:
Ken Snyder
303-275-4819

REMI
Regional Economic Models, Inc.:
413-549-1169

SCALDS (Social Costs of Alternative Land Development Scenarios)
Federal Highway Administration:
Patrick DeCorla-Souza
202-366-4076

SCARE (System Cost and Revenue Estimation model)
Federal Highway Administration:
Patrick DeCorla-Souza
202-366-4076

Smart Growth INDEX
Criterion Planners/Engineers:
Eliot Allen
503-224-8606

STEP
Environmental Protection Agency. *Technical Methods for Analyzing Pricing Measures to Reduce Transportation Emissions*. Office of Policy, Report EPA-231-R-98-06, August 1998.

StratBENCOST
Hickling Lewis Brod Inc.
Khalid Bekka
301-565-0391

STEAM
(Surface Transportation Efficiency Analysis Model)
Federal Highway Administration:
Patrick DeCorla-Souza
202-366-4076

Tool for Evaluating Neighborhood Sustainability

Canadian Mortgage and Housing
Corporation
IBI Group, Toronto, CA:
416-596-1930

TELUS
(Transportation, Economic, and Land Use System)
New Jersey Institute of Technology:
Louis Pignataro
973-596-3363

Traffic Noise Model
Information:
Federal Highway Administration
Bob Armstrong
202-366-2073
Software:
McTrans at the University of Florida:
352-392-0378, fax 3224

TRANUS
De la Barra, T. *Integrated Land Use and Transport Modeling*. Cambridge University Press, Cambridge, 1989.
Modelestica
Tomas de la Barra
(58) 2761-5432

UrbanSim
Paul Waddell
206-221-4161

Watershed Planning System
Maryland Office of Planning:
Joe Tassone
410-767-4547

Published Documents

AASHTO (1977). American Association of State Highway and Transportation Officials.
A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements. Washington, D.C., 1977.

Abraham and Hunt (2000). Abraham J. and D. Hunt (2000). Parameter Estimation Strategies for Large Scale Urban Models. Presented at the 79th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2000, Paper No. 00-0624.

Anas (1999). Anas, Alex. Application of the METROSIM Model in New York. Presented at the 77th Annual Meeting of the Transportation Research Board, January 1999.

Bardman (no date). Bardman, Cynthia A. Applicability of Biodiversity Impact Assessment Methodologies to Transportation Projects. Transportation Research Record 1601.

Batey, Madden, and Scholefield (1992). Batey, Peter W.J.; Moss Madden and Graham Scholefield. Socioeconomic Impact Assessment of Large-scale Projects using Input-Output Analysis: A Case Study of an Airport. Regional Studies Vol. 27:3, 1992.

Benfield, Raimi, and Chen (1999). Benfield, F. Kaid; Matthew D. Raimi, and Donald D.T. Chen. Once There Were Greenfields. Natural Resources Defense Council and Surface Transportation Policy Project, New York, NY, 1999.

Bowman et al. (1998). Bowman, J.L., M. Bradley, Y. Shiftan, T.K. Lawton, and M. Ben-Akiva. Demonstration of Activity-Based Model System for Portland. In World Transport Research, Selected Proceedings from the 8th World Conference on Transport Research, Antwerp, Belgium 1998.

Burchell, et al. (1999). Burchell, Robert W., et al. The Costs of Sprawl - Revisited. Transit Cooperative Research Program (TCRP) Report 39, National Academy of Sciences, Washington, D.C., 1999.

Burchell, Listokin, et al. (1994). Burchell, Robert W., David Listokin, et al. Development Impact Assessment Handbook. The Urban Land Institute, 1994.

Burchell, Listokin, and Dolphin (1985). Burchell, Robert W., David Listokin, and William R. Dolphin. The New Practitioner's Guide to Fiscal Impact Analysis. Center for Urban Policy Research, Rutgers University, 1985.

Cambridge Systematics (1998). Cambridge Systematics, Inc., With Robert Cervero and David Aschauer. Economic Impact Analysis of Transit Investments: Guidebook for Practitioners. Transit Cooperative Research Program (TCRP) Report 35, National Academy Press, Washington, D.C., 1998.

Cambridge Systematics (1999). Cambridge Systematics, Inc., with IMPEX Logistics, Eng-Wong & Taub Associates, and The Tioga Group. MORPC Inland Port III: Summary Report. Prepared for the Mid-Ohio Regional Planning Commission, March 1999. Cambridge Systematics, Inc.: Lance Grenzeback 617-354-0167

Cambridge Systmatics (2000). Cambridge Systematics, Inc. Development and Application of a Microsimulation Activity-based Model for San Francisco. Oakland, CA (PENDING PUBLICATION) Cambridge Systematics: Steven Decker or Maren Outwater 510-873-8700.

Cavalli-Sforza and Ortolano (1984). Cavalli-Sforza, Violetta, and Leonard Ortolano. Delphi Forecasts of Land Use: Transportation Interactions. Journal of Transportation Engineering Vol. 110, No. 3, 1984.

Cervero and Kockelman (1997). Cervero, R. and K. Kockelman. Travel Demand and the 3Ds: Density, Diversity, and Design, Transportation Research D Vol. 2, 1997. University of California: Berkeley, Department of City and Regional Planning Prof. Robert Cervero

Chesapeake Bay Foundation et al. (1996). Chesapeake Bay Foundation, Environmental Defense Fund, et al. A Network of Livable Communities: Evaluating Travel Behavior Effects of Alternative Transportation and Community Designs for the National Capital Region. Washington, D.C., May 1996.

Cogan (1997). Cogan, Christopher. California Biodiversity Project: Application of Ecological Data to Biodiversity Analysis. University of California, Santa Cruz, July 1997.

Criterion Planners/Engineers (2000). Criterion Planners/Engineers and Fehr & Peers Associates Inc. Smart Growth INDEX Technical Description Version 2.0. Developed for the U.S. Environmental Protection Agency, DRAFT, March 2000. Criterion Planners/Engineers: Eliot Allen 503-224-8606

De la Barra (1989). De la Barra, T. Integrated Land Use and Transport Modeling. Cambridge University Press, Cambridge, 1989.

DeCorla-Souza (2000). DeCorla-Souza, Patrick. Estimating Highway Mobility Benefits. ITE Journal Vol. 70 No. 2, February 2000. Federal Highway Administration Patrick DeCorla-Souza 202-366-4076 Delucchi (1997). Delucchi, M.A. (1997). The Annualized Social Cost of Motor Vehicle Use in the U.S., 1990-1991: Summary. Institute of Transportation Studies, University of California, Davis. University of California, Davis: Institute of Transportation Studies

Donnelly and Upton (1998). Donnelly, Rick, and William J. Upton.The Development of Integrated Land Use-Transport Models in Oregon.In Transportation, Land Use, and Air Quality: Making the Connection (conference proceedings), American Society of Civil Engineers, Reston VA (May 1998).

Douglas (2000). Douglas, Bruce. Data Collection and Modeling Requirements for Assessing Transportation Impacts of Micro-Scale Design. Prepared for the Travel Model Improvement Program (2000).

ECONorthwest and Parsons Brinckerhoff (1995). ECONorthwest and Parsons Brinckerhoff Quade and Douglas, Inc. Evaluation of Transportation Alternatives: Least-Cost Planning: Principles, Applications, and Issues.Prepared for Federal Highway Administration, Publication No. FHWA-PD-95-038, September 1995.

ECONorthwest (1996). ECONorthwest. Case Study:Testing Application of Integrated Transportation Planning Methods on System-Level Evaluation. Prepared for Puget Sound Regional Council and FHWA, June 1996. Puget Sound Regional Council Information Center 206-464-7532 Engelke (1997). Engelke, Lynette J. (ed). Activity-Based Travel Forecasting Conference Proceedings: Summary, Recommendations and Compendium of Papers.U.S. Department of Transportation, Travel Model Improvement Program, February 1997. Texas Transportation Institute Lynette Engelke 817-277-5503 ext. 226.

EPA (1998). United States Environmental Protection Agency. Technical Methods to Analyze Pricing Measures to Reduce Transportation Emissions. EPA 231-R-98-006, Office of Policy: Washington, D.C. (August 1998).

FHWA (1996). Federal Highway Administration. Community Impact Assessment: A Quick Reference for Transportation. Publication No. FHWA-PD-96-036 (September 1996). FHWA Office of Environment and Planning: 202-366-0106 FHWA (1999) Transportation Case Studies in GIS. Federal Highway Administration: Michael Culp 202-366-9229

Forkenbrock and Schweitzer (1997). Forkenbrock, David J. and Lisa A. Schweitzer. Environmental Justice and Transportation Investment Policy.Public Policy Center, University of Iowa, 1997. University of Iowa Public Policy Center David Forkenbrock 319-335-6800

Garrett and Bank (1995). Garrett. Paul A. and Fred G. Bank. The Ecosystem Approach and Transportation Development. Presented before the Standing Committee on the Environment at the Annual Meeting of the American Association of State Highway and Transportation Officials, Norfolk, Virginia, October 30, 1995. Federal Highway Administration Office of Environment and Planning Fred Bank 202-366-5004

Gillespie (1995). Gillespie, James S. I-73 Economic Impact Analysis. Virginia Transportation Research Council, Virginia Dept. of Transportation, January 1995.

Hagler Bailly (2000). Hagler Bailly Services, Inc. Guidance on Using Existing Economic Analysis Tools for Evaluating Transportation Investments. National Cooperative Highway Research Program Project 2-19(2), (PENDING PUBLICATION).

Handy and Niemeyer (1997). Handy, S.L. and D.A. Niemeyer. Measuring Accessibility: An Exploration of Issues and Alternatives. Environment and Planning A, Vol. 29, 1997.

Hirschman and Henderson. Hirschman, Ira and Michael Henderson.Methodology for Assessing Local Land Use Impacts of Highways. Transportation Research Record 1274.

Hunt and Echenique (1993) Hunt J. D., and M. H. Echenique (1993).Experiences in the application of the MEPLAN framework for land use and transportation interaction modeling. Proceedings of the 4th National Conference on the Application of Transportation Planning Methods, Daytona Beach, Florida, USA, May 1993.

Hunt (1994). Hunt, J. D. (1994). Calibrating the Naples Land Use and Transport Model. Environment and Planning 21B: 569-590.

Jaskiewicz and Russ (1998). Jaskiewicz, Frank and Troy Russ. Livability-Based MOEs for LRT Alignment Selection. In Transportation, Land Use, and Air Quality: Making the Connection (conference proceedings), American Society of Civil Engineers, Reston VA (May 1998). Glatting Jackson Kercher Anglin Lopez Reinhart Inc., Orlando, FL

Johnston and de la Barra (2000). Johnston, R.A., and T. de la Barra. "Comprehensive Regional Modeling for Long-Range Planning: Linking Integrated Urban Models and Geographic Information Systems." Transportation Research A, Vol. 34 (2000).

Landis (1995). Landis, John D. Imagining Land Use Futures: Applying the California Urban Futures Model. APA Journal, Autumn 1995. University of California - Berkeley Department of City and Regional Planning John Landis

Lee (1998). Lee, S. Sustainable spatial urban development in Kwangju in South Korea. Ph.D. Thesis. IRPUD, Dortmund, Germany (1998).

Liu (1998). Liu, Feng. Simulating for Smart Growth. In Transportation, Land Use, and Air Quality: Making the Connection (conference proceedings), American Society of Civil Engineers, Reston VA (May 1998). Baltimore Metropolitan Council Feng Liu 410-333-1750

Louis Berger Associates (1998). Louis Berger and Associates. Guidance for Estimating the Indirect Effects of Proposed Transportation Projects.National Cooperative Highway Research Program (NCHRP) Report 403: National Academy Press, Washington D.C. (1998).

MSMRC and H/SH, 1992. Middlesex Somerset Mercer Regional Council and Howard/Stein-Hudson Associates, Inc. (1992). The Impact of Various Land Use Strategies on Suburban Mobility.

Miller, Kriger, and Hunt (1999). Miller, Eric J.; David S. Kriger, and John D. Hunt. Integrated Urban Models for Simulation of Transit and Land-Use Policies: Guidelines for Implementation and Use. Transit Cooperative Research Program (TCRP) Report 48: National Academy Press, Washington D.C. (1999). University of Toronto Eric Miller

Nelson and Shakow (1996). Nelson, Dick, and Don Shakow, Least-Cost Planning: A Tool for Metropolitan Transportation Decision-Making, Transportation Research Record #1499, 1996.

Parsons Brinckerhoff Quade and Douglas (1999). Parsons Brinckerhoff Quade and Douglas. Land Use Impacts of Transportation: A Guidebook. National Cooperative Highway Research Program (NCHRP) Report 423A: National Academy Press, Washington D.C. (1999).

Porter (1997). Porter, Douglas R. U.S. 301 Transportation Study. Technical Report: Land Use and Growth Management. Prepared for U.S. 301 Transportation Study Task Force, 1997. Maryland Department of Transportation: Heidi Van Luven Putman (1996) Putman, Stephen H. "Extending DRAM Model: Theory-Practice Nexus." Transportation Research Record 1552 (1996).

RESI (1998). RESI - a Research Institute of Towson University. The Economic Impact of Maryland Highway Investment.Prepared for the Maryland State Highway Administration, 1998.

Rodier, Johnston, and Shabazian (1998). Rodier, C.J., R.A. Johnston, and D.R. Shabazian (1998). Advantages of Applying Consumer Welfare Measures to Evaluate Advanced Transit Alternatives. Transportation Research C.

Rood (1997). Rood, Timothy. Local Index of Transit Availability: Riverside County, California Case Study Report. Draft prepared for the Local Government Commission, January 1997. University of California at Berkeley Department of City and Regional Planning Timothy Rood

Sacramento Council of Governments (1999). Sacramento Area Council of Governments.Draft Environmental Impact Report on the Draft 1999 Metropolitan Transportation Plan, May 1999.

Sanchez (1999). Sanchez, Thomas, et al. Indirect Land Use and Growth Impacts: Phase I Report. Prepared for Oregon DOT, July 1999. Portland State University Thomas Sanchez 503-725-8743

Small, Noland, Chu, and Lewis (1999). Small, Kenneth A.; Robert Noland, Xuehao Chu, and David Lewis. Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost

Estimation. National Cooperative Highway Research Program (NCHRP) Report 431, National Academy Press, Washington, D.C., 1999.

Small and Rosen (1981). Small, K.A., and H.S. Rosen. Applied Welfare Economics with Discrete Choice Models. Econometrica, Vol. 49, No. 3, January 1981.

Stevenson (1998). Stevenson, Matthew Robert. Gap Analysis in Spokane County, Washington. Masters' Thesis, University of Washington, 1998.

Stopher (1976). Stopher, Peter R. Transportation Systems Evaluation. Lexington, Mass.: Lexington Books, 1976.

U.S. DOT (1997). United States Department of Transportation.Departmental Guidance for Valuation of Travel Time in Economic Analysis.Memorandum, April 9, 1997.

Vickerman (1974). Vickerman, R. W. Accessibility, Attraction, and Potential: A Review of Some Concepts and Their Use in Determining Mobility. Environment and Planning A, Vol. 6, 1974.

Waddell (1998). Waddell, Paul. The Oregon Prototype Metropolitan Land Use Model. In Transportation, Land Use, and Air Quality:Making the Connection (conference proceedings), American Society of Civil Engineers, Reston VA, May 1998. Paul Waddell 206-221-4161 Weibull (1980) Weibull, J. W. On the Numerical Measurement of Accessibility. Environment and Planning A, Vol. 12, 1980.

Weinberger (2000). Weinberger, Rachel. Commercial Property Values and Proximity to Light Rail: Calculating Benefits with a Hedonic Price Model. Paper presented at the 79th Annual Meeting of the Transportation Research Board, Washington, D.C. (January 2000).

WisDOT (1993). Wisconsin Department of Transportation (1993). Land Use in Environmental Documents: Indirect and Cumulative Effects Analysis for Project-Induced Land Development. Technical Reference Document.

Wu and Rice (1998). Wu, Yongqiang, and Robert Rice. Modeling the Impact of Land Use/Transportation Systems on the Regional Environment. In Transportation, Land Use, and Air Quality: Making the Connection (conference proceedings), American Society of Civil Engineers, Reston VA (May 1998).